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The role of cognitive control in age-related changes in well-being

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Abstract

Maintaining emotional well-being in late life is crucial for achieving successful and healthy aging. While previous research from Western cultures has documented that emotional well-being improves as individuals get older, previous research provided mixed evidence on the effects of age on well-being in Eastern Asian cultures. However, previous studies in East Asia do not always take into account the effects of cognitive control – an ability which has been considered as a key to enable older adults to regulate their emotions. In the current study, we tested whether cognitive control abilities interact with age in determining individuals' well-being in 59 Japanese females (age range: 26-79; M_{age} = 64.95). Participants' mental health and mental fatigue were tracked for 5 years together with their cognitive control abilities. We found that as individuals became older, they showed improved mental health and decreased mental fatigue. In addition, for mental fatigue, we found a quadratic effect of age which was further qualified by baseline cognitive control abilities; in those who had a lower level of cognitive control abilities, mental fatigue declined until the mid 60s, at which point it started increasing (a U-shape effect). In contrast, in those who had a higher level of cognitive control ability, mental fatigue showed a steady decrease with age even after their mid-60s. These results suggest that whether advancing age is associated with positive vs. negative changes in well-being depends on cognitive control abilities and that preserved cognitive control is a key to maintain well-being in late life.

Contribution to the Field Statement

Subjective well-being and happiness are vital for maintaining health and cognitive functioning in late life. Research primarily from Western cultures revealed that as individuals get older, their emotional well-being improves when they maintain cognitive control abilities (i.e., individuals' ability to flexibly coordinate thoughts and actions based on their goals and context). However, we do not know if the same is true in East Asian cultures. Here we tested whether cognitive control is related to age-related changes in well-being in a sample of Japanese females. We found that as individuals became older, their well-being improved. However, the effects of age were also different depending on cognitive control abilities. In those who had a lower level of cognitive control, age stopped having beneficial effects on well-being in the mid 60s, and age started having a negative impact on well-being after this point. In contrast, a higher level of cognitive control enabled individuals to show improved well-being due to age even after the age of 65. These results are largely consistent with previous findings from Western cultures and suggest that cognitive control is key to maintain well-being in old age across different cultures.

Introduction

Aging is typically associated with a range of negative experiences, such as declines in physical functioning and a loss of close friends. Nevertheless, when older adults are invited to lab experiments, they are more likely to pay attention to and remember positive information than negative information (Knight et al., 2007; Mather & Knight, 2005; Reed, Chan, & Mikels, 2014; Sakaki, Nga, & Mather, 2013). This age-by-valence interaction has been called the positivity effect. In addition to the positivity effect in memory and attention, older adults also report better emotional experiences, reduced negative emotions, and improved well-being than do younger adults (Carstensen et al., 2011; Charles et al., 2010; Charles, Reynolds, & Gatz, 2001; Riediger, Schmiedek, Wagner, & Lindenberger, 2009; Steptoe, Deaton, & Stone, 2015). A prominent theory to explain the positivity effect and better well-being with age is the socioemotional selectivity theory (SST; Scheibe & Carstensen, 2010). The SST posits that as individuals get older, they perceive time left in their life as being more limited. As a result, older adults are more likely to prioritize emotion regulation goals and invest more effort in what is most important for their emotional well-being than do younger adults. This motivational shift is considered to result in preferential processing of positive stimuli as well as better emotional experiences in old age.

According to the SST, the positivity effect and better well-being with age should be driven by one’s perception of the limited time left in their life. Given that chronological age is typically associated with limited time perspective across many cultures (e.g., Fung & Carstensen, 2006; Lang & Carstensen, 2002), it is plausible that the positivity effect and better well-being with age are observed irrespective of cultures. However, previous research does not always support this prediction and evidence from Eastern Asia is rather mixed (for a review see Fung, 2013). For example, while American individuals show increased dispositional optimism with age, Chinese individuals show decreased dispositional optimism with age (You, Fung, & Isaacowitz, 2009). A recent large-scale cross-sectional study also reveals a smaller age-related improvement in emotional experiences in Japan than in the US (Grossmann, Karasawa, Kan, & Kitayama, 2014). In addition, studies on attention and memory failed to observe the positivity effect in East Asian cultures (e.g., Fung, Isaacowitz, Lu, & Li, 2010). For example, while older adults in Western cultures typically show selective attention to positive stimuli over negative stimuli (Mather & Carstensen, 2003), Chinese older adults looked away from positive stimuli (Fung, Isaacowitz, et al., 2008).

In contrast, other studies suggest that the age-related positivity effect is not limited to Western cultures and can be observed in Eastern Asian cultures (Fung & Carstensen, 2006). When Korean participants were compared to US participants, Korean older adults show a similar age-related positivity effect to US older adults in memory tasks (Ko, Lee, Yoon, Kwon, & Mather, 2011; Kwon, Scheibe, Samanez-Larkin, Tsai, & Carstensen, 2009). A recent study also reveals that Chinese older adults demonstrate larger preferences toward positive stimuli in attention (Knight et al., 2007) as observed in US older adults (Wang, He, Jia, Tian, & Benson, 2015).

This inconsistent pattern of results may be driven by individual differences in factors relevant to the positivity effect and well-being (Fung et al., 2010). One possible source of individual differences is cognitive control (Mather & Carstensen, 2005). Cognitive control is critical for achieving emotion regulation (Opitz, Gross, & Urry, 2012; Urry & Gross, 2010) but it is one of the most vulnerable processes of age-related decline (e.g., Fjell, Sneve, Grydeland, Storsve, & Walhovd, 2016; Milham et al., 2002). Research from Western cultures suggests that this age-related decline in the cognitive control mechanisms can lead to weaker positivity effects and worse well-being in the late old age. For example, the positivity effect in memory and attention is attenuated when older adults have limited resources in their executive functioning (Knight et al., 2007; Mather & Knight, 2005; Petrican, Moscovitch, & Schimmack, 2008). Individual differences in the positivity effect in memory were also correlated with individual differences in cognitive control (Mather & Knight, 2005; Sakaki, Raw, Findlay, & Thottam, 2019).

Previous research on well-being in old age further suggests that preserved cognitive function, including cognitive control abilities, plays key roles in older adults' well-being. For example, cross-sectional studies demonstrated that higher general intelligence is associated with better emotional experiences in older adults (Gale et al., 2012; Isaacowitz & Smith, 2003). Higher cognitive control abilities are also correlated with higher scores in the purpose in life (Lewis, Turiano, Payne, & Hill, 2017) — one of the key domains of psychological well-being (Ryff, 1989). Longitudinal studies also show that better processing speed at baseline is associated with subsequent better life satisfaction (Enkvist, Ekström, & Elmståhl, 2013). Recent research further extends these findings and indicates that cognitive decline predicts subsequent level of well-being in older adults (Allerhand, Gale, & Deary, 2014; Godin, Armstrong, Wallace, Rockwood, & Andrew, 2018; Wilson et al., 2013).

Despite its importance, most of the previous studies on the positivity effect and well-being in East Asian cultures did not consider the effects of cognitive control. The current study aims to address the role of cognitive control in longitudinal changes in well-being in Japanese participants. We tracked Japanese individuals' well-being and cognitive control performance for up to 5 years, used growth curve modeling, and tested whether the baseline cognitive control performance is critical for individuals to show the age-related improvements in well-being. We hypothesized that a) individuals' well-being improves as they get older, but b) this effect of age is qualified by the baseline cognitive control abilities, such that those who are low in their cognitive control abilities show smaller improvements in their well-being with age especially in the late adulthood when their cognitive control mechanisms start declining.

Materials and Method

Participants

Fifty-nine Japanese females participated in the study. Four participants did not complete the digit backward task and another participant did not complete the digit backward task and the Stroop task. Given that these tasks were used to estimate cognitive control abilities, data from the five participants were excluded; thus analyses were performed on data from 54 participants (age range at Wave 1: 26 to 79; *M*age = 64.95, *SD* = 11.08). Participants were recruited through advertisements in local newspapers during July 2011, from Sendai city around the Tohoku University, Japan. We recruited as many participants as possible during this recruitment period. Data were collected 12 times between August 2011 and June 2016 (Wave 1: August 2011; Wave 2: September 2011; Wave 3: November 2011; Wave 4: February 2012; Wave 5: September 2012; Wave 6: February 2013; Wave 7: August 2013; Wave 8: February 2014; Wave 9: August 2014; Wave 10: March 2015; Wave 11: September 2015; Wave 12: June 2016; a total number of data points = 382). None of the participants had a history of the following mental disorders including schizophrenia, bipolar disorder, major depressive disorder, anxiety disorders, obsessive compulsive disorder and disease known to affect the central nervous system, such as thyroid disease, multiple sclerosis, Parkinson disease, stroke, severe hypertension (systolic blood pressure over 180, diastolic blood pressure over 110), and diabetes. None of them took drugs that affected cognitive function (including benzodiazepines, antidepressants, and other central nervous agents). None of them reported as being diagnosed as dementia or MCI (Mild Cognitive Impairment). They received 1,000 JPY (approx. $10)/hour for their participation.

Instruments

We used a Japanese version of the subjective well-being inventory (SUBI) which consists of two subscales of well-being (Sell & Nagpal, 1992); a) 19 items on mental health (e.g., “Do you feel your life is interesting?”; “Do you normally accomplish what you want to?”) and b) 21 items on mental fatigue (e.g., “Do you feel disturbed by feelings of anxiety and tension?”; “Do you sometimes feel sad without reason?”). Participants responded to each question on a scale of 1 ("not so much"), 2 ("somewhat agree"), and 3 ("strongly agree"). The reliability and the validity of the Japanese version were reported in a previous study (Ono & Yoshimura, 2001). Higher mental health scores indicate a higher degree of subjective health and higher mental fatigue scores indicate a higher degree of mental fatigue (i.e., low subjective well-being).

Procedure

The data analyzed in this paper were collected as a part of a more extensive study (see Supplemental Materials for other measures we obtained). Participants were told that the aim of the study was to examine the longitudinal changes in women’s mental functioning. For each time point, a paper-based questionnaire on SUBI was mailed to participants and completed at home. Participants next completed the lab session, where we administered the paper-version Stroop task (Hakoda & Sasaki, 1990; Takeuchi et al., 2011), the Japanese Adult Reading Test (JART; Matsuoka, Uno, Kasai, Koyama, & Kim, 2006), verbal memory using a short-paragraph story (Wechsler, 1987), the digit forward/backward task from the WAIS (Wechsler, 1997) in groups (which included 1 to 6 participants; see Supplemental Materials for details).

Data analysis

The primary goal of this study was to test the role of cognitive control abilities. Therefore, we focused on Stroop and Digit Backward performance as a measure of individuals' cognitive control ability at Wave 1 and created a composite score based on performance in these two tasks; A similar measure was computed in previous studies as well (Davis, Marra, Najafzadeh, & Liu-Ambrose, 2010). The Stroop interference score was reversed so that a higher score reflects a better cognitive control ability. We then created a single cognitive control index by averaging the z-scores of the Stroop interference score and backward digit span task, $r(52) = .45$, $p < .001$.

While none of our participants reported as being clinically diagnosed with dementia nor MCI, we ran another analysis to account for the effects of possible dementia/MCI cases. Specifically, we created another composite measure based on the Wechsler logical memory and vocabulary performance, both of which is typically correlated with performance in standard screening batteries for dementia (Chapman et al., 2016; Raghavan et al., 2013). This additional composite score was used as a covariate in our supplemental analyses to rule out the possibility that the effects of cognitive control abilities are driven by general cognitive declines associated with dementia or MCI (see Supplemental Results); the correlation between the two composite scores was $r(48) = .37$, $p < .001$.

Results

Table 1 reports the descriptive statistics of the main variables for each time point. The attrition rate for the second wave was 3.70%, increased over time and was 74.07% at Wave 12 (Table 1). We compared the variables reported in this paper at Wave 1 between participants who participated all of the assessments and those who did not, but did not observe any significant difference between the groups; SUBI Mental Health, $t(24) = 2.06$, $p = .785$, d =0.08, SUBI Mental Fatigue $t(18) = 2.10$, $p = .123$, d = 0.54, and the cognitive control index, $t(23) = 2.07$, $p = .373$, $d = 0.28$.

Table 1 Descriptives of Variables

	SUBI Mental Health			SUBI Mental Fatigue			Interference rates of stroop task		Backward recall task	
	M (*SD*)	α	*N*	*M* (*SD*)	α	*N*	*M* (*SD*)	*N*	*M* (*SD*)	*N*
Wave 1	37.28 (5.21)	.84	54	32.92 (5.59)	.83	54	16.65 (17.23)	54	6.59 (2.14)	54
Wave 2	37.15 (5.84)	.88	52	32.25 (5.53)	.82	52	15.26 (15.84)	51	6.46 (2.31)	50
Wave 3	38.43 (4.87)	.79	48	31.71 (5.10)	.80	48	12.69 (16.73)	46	6.91 (2.58)	46
Wave 4	37.47 (4.31)	.76	44	31.25 (5.03)	.82	43	11.46 (9.41)	44	6.98 (2.76)	43
Wave 5	38.91 (5.30)	.84	36	31.63 (5.10)	.80	36	8.51 (12.83)	36	6.92 (2.75)	36
Wave 6	38.03 (4.21)	.80	32	30.64 (4.01)	.73	32	11.09 (10.97)	32	6.53 (2.72)	32
Wave 7	39.09 (5.41)	.87	27	31.37 (4.82)	.81	27	12.28 (12.73)	26	6.54 (2.42)	26
Wave 8	39.38 (6.92)	.92	20	31.36 (4.13)	.71	20	16.59 (11.33)	20	6.65 (2.72)	20
Wave 9	38.97 (6.83)	.91	19	31.35 (4.92)	.81	19	14.70 (8.90)	19	7.00 (2.11)	19
Wave 10	37.70 (5.91)	.88	19	32.29 (4.27)	.69	19	14.03 (9.22)	17	6.53 (2.48)	17
Wave 11	37.78 (5.74)	.88	17	30.83 (4.39)	.76	17	14.31 (17.50)	17	7.18 (2.51)	17
Wave 12	38.30 (6.85)	.93	14	32.32 (4.37)	.72	14	9.87 (11.77)	14	6.57 (2.44)	14

notes: α shows consistency within the scale.

Growth curve analysis of well-being

We next tested our main prediction that baseline cognitive control abilities predict age-related changes in well-being. To test this prediction, we used a growth curve model on SUBI mental health and SUBI mental fatigue scores (they were modeled separately) with cognitive control assessed at Wave 1 as a predictor. The model was specified and estimated by hierarchical linear modeling, using the software R version 3.6.0 (R Core Team, 2017) and the 'lme4' package (version 1.1-21), with Waves as level-1 units and participants as level-2 units. To examine how well-being changed as a function of participants' age, the model included the linear and quadratic effects of age as level-1 predictors. The model also included the random intercept and random slopes of the linear and the quadratic effects of age. The model is as follows:

$$\text{Level-1: } y_{ij} = \beta_{0j} + \beta_{1j}(\text{Age}_{ij}) + \beta_{2j}(\text{Age}_{ij})^2 + r_{ij}$$

$$\text{Level-2: } \beta_{0j} = \gamma_{00} + \gamma_{01}(\text{Cognitive control}_j) + u_{0j}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}(\text{Cognitive control}_j) + u_{1j}$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21}(\text{Cognitive control}_j) + u_{2j}$$

y_{ij} was the well-being (mental health or mental fatigue scores) of the participant *j* at Wave *i*. Age_{ij} is the age of participant *j* at Wave *i* (to facilitate interpretation and computation, we divided the actual age by 10), with grand-mean centered. β_{0j} was the intercept of participant *j* (the estimated value of the dependent variable at Wave 1), whereas β_{1j} and β_{2j} represent the linear and quadratic effects of age for participant *j*. Cognitive control$_j$ is the cognitive control score of participant *j* at Wave 1, and this variable was included to explain individual differences in the intercept and slopes (β_{0j} , β_{1j} , and β_{2j}). u_{0j}, u_{1j}, and u_{2j} refer to the random intercept and random slopes between participants which were unexplained by the cognitive control scores. r_{ij} is the error term following a normal distribution. Given that the model described above did not converge when the dependent variable was a mental health score, we removed the random slope for the quadratic effects of age for the mental health score.

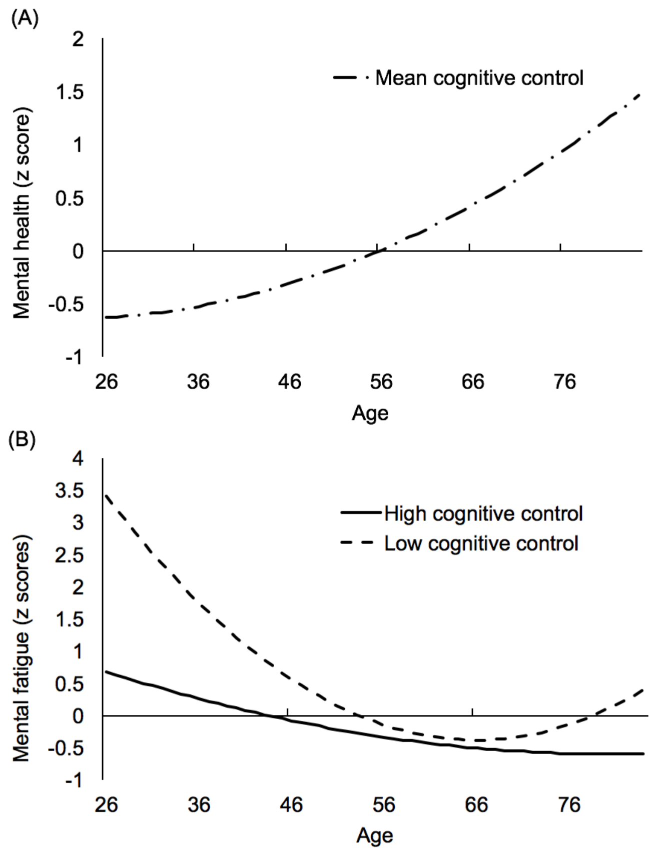

Figure 1. (A) Estimation of the growth curve of mental health. The line represents the mental health score when entering the mean cognitive control score. (B) Estimation of the growth curve of mental fatigue. The solid line represents higher cognitive control abilities at Wave 1; and the dashed line represents lower cognitive control abilities at Wave 1 (+/- 1 *SD* than the mean respectively).

Consistent with the age-related improvement in well-being documented in the literature, we found the positive effects of age on mental health scores (Table 2), γ_{10} = 0.361, $p < .05$, indicating that participants' mental health improved as they became older. The quadratic effects of age, cognitive control, and any interactions between age and cognitive control were not significant (Figure 1A).

Table 2. Results from multilevel growth curve analyses on two aspects of subjective well-being

	Mental health			Mental fatigue		
Fixed effects	Coefficient		*p*	Coefficient		*p*
Intercept	-0.03		0.841	-0.21		0.124
Cognitive control	0.04		0.813	-0.13		0.434
Age	0.36	*	0.021	-0.37	*	0.001
Age*Cognitive control	-0.31		0.092	0.18		0.138
Age^2	0.05		0.571	0.14	*	0.007
Age^2*Cognitive control	-0.03		0.730	-0.12	*	0.013
Random effects	Variance			Variance		
Intercept	0.73			0.77		
Age	0.15			0.01		
Age^2	NA			0.01		

Note: Age^2 stands for the quadratic effects of age.

A similar analysis on mental fatigue also revealed a significant effect of age (Table 2), γ_{10} = -0.369, p = .001, which indicates less mental fatigue (i.e. better well-being) as participants became older, again supporting the idea of better well-being with age. In addition, we found a significant positive quadratic effect of age, γ_{20} = 0.140, $p < .01$, which was further moderated by cognitive control at Wave 1, γ_{21} = -0.116, $p < .05$. Figure 1B plotted the growth curve for those with high (mean + 1SD) and low (mean - 1SD) cognitive control scores at Wave 1. Participants with lower cognitive control levels at Wave 1 showed the U-shape effects of age, suggesting that their well-being improved until mid-60 at which point it started decreasing. These results are consistent with previous results that the age-related improvements in well-being stop emerging after a certain point (Carstensen et al., 2011; Gana, Saada, & Amieva, 2015; Jivraj, Nazroo, Vanhoutte, & Chandola, 2014). In contrast, individuals with higher levels of cognitive control at Wave 1 showed a linear positive effect of age, where increasing age led to less mental fatigue (i.e. greater subjective well-being) even after the age of 65. In both mental fatigue and mental health, the results remained unchanged when including an additional covariate based on vocabulary and memory performance (see S-Table 1).

Growth-curve analysis of cognitive control

While our primary focus is on the effects of cognitive control on age-related changes in well-being, previous research shows that well-being also protects against age-related changes in cognitive function (Allerhand et al., 2014; Wilson et al., 2013). To test this possibility, we examined whether and how the well-being assessed at Wave 1 affects the growth curve of cognitive control. The specified growth-curve model was similar to the one used in the previous section but now the dependent variable was the cognitive control scores. Mental health and mental fatigues scores at Wave 1 were included simultaneously as level-2 predictors to explain the individual differences in the linear and quadratic effects of age (see below).

Level-1: $yij = \beta_{0j} + \beta_{1j}(\text{Age}) + \beta_{2j}(\text{Age}^2) + r_{ij}$

$$\text{Level-2: } \beta_{0j} = \gamma_{00} + \gamma_{01}\,(\text{mental health}_j) + \gamma_{02}\,(\text{mental fatigue}_j) + u$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11}\,(\text{mental health}_j) + \gamma_{12}\,(\text{mental fatigue}_j) + u_{1j}$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21}\,(\text{mental health}_j) + \gamma_{22}\,(\text{mental fatigue}_j) + u_{2j}$$

This analysis revealed that neither of the mental health measures at Wave 1 predicted age-related changes in cognitive control (*p*s = .540, .273; Table 3). However, we found a significant linear effect of age, indicating that as individuals get older, their cognitive control ability declines.

Table 3 Results from multilevel growth curve analyses on cognitive control performance

Fixed effects	Coefficient		*p*
Intercept	0.074		0.442
Mental health (wave 1)	-0.072		0.540
Mental fatigue (wave 1)	-0.130		0.273
Age	-0.358	*	0.002
Age*Mental health	-0.092		0.411
Age*Mental fatigue	-0.205		0.123
Age^2	0.005		0.937
Age^2*Mental health	0.004		0.953
Age^2*Mental fatigue	-0.071		0.277
Random effects	Variance		
Intercept	0.307		
Age	0.061		
Age^2	0.212		

Note: Age^2 stands for the quadratic effects of age.

Discussion

Well-being in old age has been associated with a better survival rate and lower risks to various diseases (Boehm & Kubzansky, 2012; Steptoe & Wardle, 2011), suggesting that it is key for achieving successful aging. Research done in Western cultures often demonstrate that as individuals get older, they preferentially process emotionally positive information (Knight et al., 2007; Mather & Knight, 2005; Reed et al., 2014; Sakaki et al., 2013) and report better well-being (Carstensen et al., 2011; Charles et al., 2010; Charles et al., 2001; Riediger et al., 2009; Steptoe et al., 2015). In contrast, studies in Eastern Asian cultures have provided mixed evidence (Fung et al., 2010; Fung, Isaacowitz, et al., 2008; Grossmann et al., 2014). Yet many of these studies done in East Asian culture did not consider individual differences in cognitive control – an ability which has been considered to play key role in the age-related positivity effect and wellbeing in older adults.

In the current study, longitudinal data on well-being and cognitive control abilities from Japanese females were analyzed to address a) whether age has positive impacts on well-being as observed in Western culture and b) whether such effects of age on well-being are modulated by the levels of cognitive control. We measured two aspects of subjective well-being (one on mental health and another on mental fatigue) and found that advancing age is associated with increased levels of happiness and decreased levels of mental fatigue, replicating the age-related increases in well-being in this sample. In addition to the main effects of age, the analysis on the mental fatigue score revealed that age has quadratic effects on mental fatigue that were further qualified by the baseline cognitive control ability. Specifically, in those who had lower levels of cognitive control ability at baseline, advancing age stopped having positive impacts on well-being after the mid 60s as observed in previous studies (Carstensen et al., 2011; Gana et al., 2015; Jivraj et al., 2014). In contrast, those who had higher levels of cognitive control showed a steady decrease in their mental fatigue level even after their mid 60s. These results support findings in previous studies from Western cultures and suggest that the cognitive control plays key roles in protecting subjective well-being when individuals get older even in East Asia.

Our results support the SST and suggest that the effects of age on well-being are similar across Western and East Asian cultures. However, it does not mean that individuals achieve better well-being in a similar manner across different cultures. In fact, past studies suggest that people from different cultures often take different behaviors to achieve better well-being (Tsai, 2017). For example, in East Asian cultures that are more collectivistic, people tend to focus more on interpersonal relatedness to achieve better well-being than those in Western cultures (Fung, Stoeber, Yeung, & Lang, 2008). In addition, unlike Westerns who value high arousal positive states, East Asians value low arousal positive states. They, therefore, take behavior that induces low arousal positive emotions to achieve better well-being (Tsai, Miao, & Seppala, 2007). Future research needs to further examine the interaction between age and cultures on strategies/behavior people take to achieve better well-being.

In addition to the effects of age on well-being, we also examined the effects of age on cognitive control abilities and confirmed the previous findings that cognitive control abilities decline as individuals get older as documented in the literature (e.g., Fjell et al., 2016; Milham et al., 2002; Tucker-Drob, 2011). However, while previous research demonstrates that well-being helps protect against age-related changes in cognitive function (Allerhand et al., 2014; Wilson et al., 2013), we did not find significant effects of well-being on cognitive control abilities. The lack of significant effects of well-being may be driven by a relatively small sample size in this study. Future studies need to use a larger sample to examine the interaction between well-being and cognitive control abilities.

Another question for future research concerns similarities and differences in the mechanisms underlying the age-related increases in well-being vs. the age-related positivity effect in attention and memory. Previous research has documented that as individuals get older, they show improved well-being as well as more preferences for positive over negative materials in attention and memory. Both these two phenomena have been explained by the SST (Carstensen & DeLiema, 2018; Steptoe et al., 2015). Our results support these notions and suggest that the effects of age on well-being and emotional processing are at least partly explained by the same factor – cognitive control abilities. However, there should be other factors that are uniquely associated with each of them. In fact, individuals' well-being is affected by a number of factors that are not typically implicated in the positivity effect in attention and memory, including social network (Golden et al., 2009; Litwin & Shiovitz-Ezra, 2010), health/disabilities (Fonseca, Kapteyn, Lee, Zamarro, & Feeney, 2014), and prosocial behavior (Aknin et al., 2013). Future research needs to examine differences and similarities in the underlying mechanisms between the age-related changes in well-being and the age-related positivity effect in attention and memory.

There are also other important limitations of this study. First, we had a relatively large difference in baseline age across participants. While this allowed us to estimate a growth curve from middle- to old age, it may have introduced a potential confound across those in different age groups. The large baseline age differences also posed an analytic challenge in examining short-term potential reciprocal effects between cognitive control and well-being. While there is a substantial body of work on the reciprocal interaction between well-being and cognitive function (e.g., Allerhand et al., 2014; Boyle, Buchman, Barnes, & Bennett, 2010; Lewis et al., 2017), these large-scaled studies primarily concerned American or West European samples. Future similar studies on different cultures are critical for understanding whether age, cognitive control and well-being interact similarly or differently depending on individuals' background.

Second, our sample size was relatively small and limited to females. Although the small sample size is compromised by the relatively large number of data points we had (n = 382; Curran, Obeidat, & Losardo, 2010), the large number of assessments we administered per participant (n = 12) resulted in a high attrition rate, which may have resulted in biased estimates. In addition, previous research has documented sex differences in well-being (Pinquart & Sörensen, 2001) as well as in cognitive control

(Tun & Lachman, 2008). Furthermore, females experience age-related changes that are not observed in males (e.g., menopause), which can affect cognitive control abilities (Herrera, Hodis, Mack, & Mather, 2017; Sakaki & Mather, 2012). Future research, therefore, needs to examine whether our results will be replicated in a bigger sample, and systematically address whether females and males show similar interactions between age and cognitive control abilities. Given general difficulties in maintaining older adult participants in longitudinal studies (Bonk, 2010), such future research may need to consider using a smaller number of assessments per participant to ensure reasonable statistical power in a cost-effective manner.

Third, while our study found a steady increase in well-being in old age, all of our participants were healthy adults. In contrast, cognitive control abilities show a rapid decline in proximity to death (Johansson et al., 2004; MacDonald, Hultsch, & Dixon, 2011). Well-being is also known to rapidly decrease in proximity to death (Gerstorf et al., 2010). In addition, we did not include a formal screening test for dementia or MCI. Further studies need to consider the effects of systematic dysfunction associated with death as well as dementia. Fourth, the current study focused on only one source of individual differences that modulate the age-related changes in well-being – cognitive control. Given that previous studies suggest that other individual differences in goals also play a role in the cultural differences in age-related changes in emotional experiences (Fung et al., 2010), future research should take into account the effects of these additional variables to fully understand how age affects individuals' well-being across different cultures.

Author contributions

YA, RN, MS, KM and RK designed the study; RN and RK collected data, YA, MS and KM performed analyses; YA and MS wrote an initial draft and all authors approved the final version of the manuscript.

Conflict of Interest

This study was based on an industry–academic collaboration at the Tohoku University (http://www2.idac.tohoku.ac.jp/dep/sairc/square.html) and supported by Curves Japan Co., Ltd. However, the funding source had no involvement in the study design, data collection, data analysis, the interpretation of data, and writing up the manuscript.

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